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The multicriteria assessment of multi-storey office building energy performance

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Abstract

Global trends indicate that the industrial development of countries requires increasingly larger energy resources. Energy resources that are most wildly used in industry are non-renewable natural resources. Therefore, the energy savings and the energy efficiency are given greater consideration. The advancement of information technology enables more frequent use of computer software tools such as BIM for this purpose. Computer-aided modeling makes it possible to simulate buildings and processes needed to achieve the result before they actually take place. According to this principle, the article presents an assessment model for an analysis of design variants of multi-storey office building.

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Keywords: Energy efficiency, building information modelling,energy simulation, CO_2 emission.

1. Introduction

Over the past few decades, the increase in temperatures at the Earth's surface and in oceans, known as universal or global warming, has been recorded. Human activities contribute to climate change by burning minerals for energy production. Global trends make that the industrial development of countries requires increasingly larger energy resources, the same trend is typical of the buildings sector. A reckless need to use one or another kind of energy and

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materials is evidenced in each individual stage of the life cycle of the building (design, manufacture, construction, operation and demolition) [1,2]. In order to bring the situation under control, the needs for enormous energy consumption and the savings of the energy resources are given more serious consideration in developing the legal framework and using of instruments such as building information modelling (BIM) [3,4].

The European Union and non-EU allies are working in cooperation to develop the legal framework and find possible solutions for the prevention and mitigation of global warming-related effects to ensure resource conservation and reduction of carbon dioxide emissions into the environment during activities such as mining, manufacturing, etc. thereby reducing greenhouse gas emissions. Furthermore, new buildings must meet exceptionally strict requirements in order to increase energy efficiency and renewable energy on the overall energy balance sheet and to reduce greenhouse gas emissions [2,5,6].

The aim of this article is to develop a building assessment methodology and to establish dependencies of the parameters of office buildings related to energy efficiency in the early design stage.

2. Methodology

The hypothesis of the research is that the high level of the building energy efficiency is not (or not always) proportional to the investment, i.e. additional investment does not (or not always) bring benefits from economic and environmental points of view. An assessment model for an analysis of design variants of multi-storey office building is presented in Figure 1.

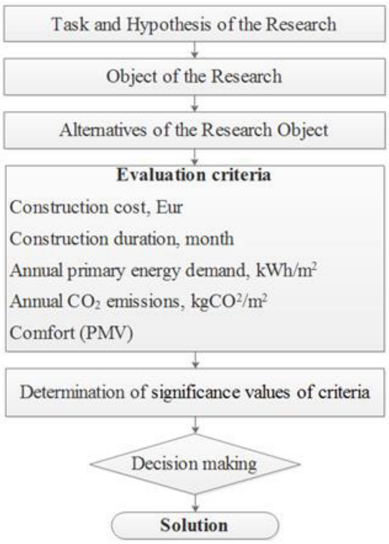

Fig. 1. Model for assessment of research project.

Three design variants of the office building are analyzed in this article. Therefore, the first design variant of the building is made according to the technical design solutions made in 2008 (energy efficiency class C). The second design variant is made according to class B energy efficiency solutions and the third design variant is based on detail design solutions made in 2013 (energy efficiency class A).Each design variant of the case study is evaluated in terms of the selected assessment criteria such as construction cost, construction duration, energy efficiency, environmental impact and comfort [4,5].

Construction cost is used as criterion in order to assess the cost of general construction works and installation of engineering systems, expressed in thousand Euros (x_1). All costs calculated as at 10/2013 because the project was carried out in that period. Construction duration is used to evaluate the total duration for installation of load-bearing structures, ventilated and glass façades, roofing, and engineering systems, expressed in months (x_2). An amount of annual primary energy is used as the energetic criterion, expressed in kWh/m^2 (x_3). An amount of annual CO_2

emissions is used as the ecological criterion, $kgCO_2/m^2$ (x_4). Predicted Mean Vote Index (PMV), which predicts the mean response of a larger group of people according to the ASHRAE thermal sensation scale, is used as the comfort criterion [8], (x_5). The values of construction cost and duration for each model have been obtained using the methods of estimation, time schedule, calculation and modelling [6]. The values of the primary energy demand and PMV index have been determined using an energy simulation software Design Builder.

In order to determine the best alternative, calculations were made using ARAS method. A multi-criteria decision making method Additive Ratio ASsessment (ARAS) is used for the final decision making in the rank of the design variants of the building [7]. The calculations includes the following 4 alternatives: A_1 ($C_{calc.}$), A_2 ($B_{calc.}$), A_3 ($A_{calc.}$) based on the initial values of criteria and A_0 – optimal values. The relative significances of criteria (criteria weights) w_j are determined according to the survey, involved 20 construction-related experts. In this article all selected criteria are minimized. Therefore, the criteria, whose preferable values are minimal, are normalized by applying two-stage procedure:

$$x_{ij} = \frac{1}{x_{ij}^*}; \bar{x}_{ij} = \frac{x_{ij}}{\sum_{i=0}^{m} x_{ij}}. \tag{1}$$

The sum of weights w_j must be limited to requirement:

$$\sum_{j=1}^{n} w_j = 1. \tag{2}$$

Normalized-weighted values of all the criteria are calculated as follows:

$$x_{ij} = \bar{x}_{ij} w_j; i = \overline{0,m}, \tag{3}$$

where w_j is the weight (importance) of the j criterion and x_{ij} is the normalized rating of the j criterion.

The following task is determining values of optimality function:

$$S_i = \sum_{j=1}^{n} x_{ij}; i = \overline{0,m}, \tag{4}$$

where S_i is the value of optimality function of i alternative.

3. Case study

The research object is the multi-storey office building located in Vilnius (Lithuania). Total floor area of this building is 9560 m^2 (21 floors). The computer modelling tools have been used for three models made according to energy efficiency classes C, B, A.

In Lithuania, energy performance at the design stage is regulated by the Construction Technical Regulation STR 2.05.01:2013 "Design of Energy Performance of Buildings" [9]. The Regulation was implemented in accordance with the Directive 2010/31/EU of the European Parliament. The heat transfer coefficients (U-values) presented in Table 1 are based on the requirements of the Regulation and contains values measured in W/m^2 K, for the building envelope elements according to the energy classes.

Table 1. Heat transfer coefficients (U-values) in W/m^2 K of building envelope according to the energy efficiency classes.

Building envelope elements	Energy efficiency classes		
	C	B	A
Roof	0.196	0.155	0.109

Slabs adjacent to the outside	0.200	0.176	0.103
Slabs above unheated basements	0.225	0.174	0.143
Walls	0.243	0.180	0.119
Windows and glazing	1.600	1.300	0.530
Doors, gates	1.600	1.600	1.300

4. Assessment data and results

The initial values of selected criteria are determined according to the data obtained from the project developer during the building energy modelling for the different energy efficiency classes (A, B and C). The initial values of criteria are provided in Table 2.

Table 2. Summary of the initial criteria values for different energy efficiency classes.

Criteria		Energy efficiency classes		
		C	B	A
Construction cost	Thousands €	3846.59	3831.68	4618.75
Construction duration	months	10.50	10.90	12.10
Annual primary energy demand	kWh/m^2	240	228	205
Annual CO_2 emissions	$kgCO_2/m^2$	51.7	49.0	44.1
Comfort (PMV)		1.164	1.235	2.860

The biggest value is the best, and the least one is the worst. A weighted–normalized decision making matrix for ARAS method with final results is presented in Table 3.

Table 3. A weighted–normalized decision making matrix for ARAS method with final results.

Criteria	Weight of criteria	Optimization direction	Alternative design variants			
			A_1 *C calc.*	A_2 *B calc.*	A_3 *A calc.*	A_0
Construction cost (x_1)	0.300	min	0.0779	0.0782	0.0649	0.0789
Construction duration (x_2)	0.090	min	0.0232	0.0223	0.0201	0.0243
Annual primary energy demand (x_3)	0.190	min	0.0430	0.0452	0.0503	0.0515
Annual CO2 emissions (x_4)	0.260	min	0.0575	0.0607	0.0674	0.0743
Comfort (x_5)	0.160	min	0.0470	0.0443	0.0191	0.0479
Index of effectiveness *R*			0.2486	0.2507	0.2219	0.2788

A priority sequence of the alternatives is as follows: $A_2 \succ A_1 \succ A_3$. Therefore, considering selected three design variants of the multi-storey office building, the best solution is the alternative A_2.

5. Conclusions

1. The present article has confirmed the probability that the high level of the building energy efficiency is not (or not always) proportional to the investment, i.e. additional investment does not bring benefits from economic and environmental points of view.
2. The results of the energy simulation of building design variants showed that:

- in case of energy efficiency class A, the annual primary energy demand and the amount of CO_2 emissions are lower by 10 % comparing with the design variant of class B;
- and lower by 14.6 % in comparison with the variant of class C.

3. Following the simulation results of the building variants, due to the higher requirements for building tightness and thermal characteristics, the average annual value of PMV index has increased up to 2.86 (feeling hot)in case of building variant of class A. The building is overheating thereby causing discomfort and a significant increase in electricity demand for air cooling. The additional solar control measures, which shall further raise the construction cost, must be implemented.
4. The analysis of design variants of the office building and the assessment of the above mentioned criteria have shown that the best alternative is A_2 (energy efficiency class B). However, the assumption of the best alternative should be based on a more detailed examination in terms of other criteria for economic efficiency, environmental impact and energy efficiency.

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